1. Radiation ~~Physics~~
2. Photosynthesis
3 Transpiration

Interim Report 62-4

THE ENERGY BUDGET AT THE EARTH'S SURFACE

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Contribution by:

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Radiant Energy Exchanges within a Corn Crop Canopy and Implications in Water Use Efficiency

Northeast Branch
Soil and Water Conservation Research Division
Agricultural Research Service
U. S. Department of Agriculture

in cooperation with

N. Y. S. College of Agriculture
Cornell University
Ithaca, New York

for

Meterology Department
U. S. Army Electronic Proving Ground
Fort Huachuca, Arizona

JULY 1962

Bailey Hall, Ithaca, N. Y.

INTERIM REPORT 62-4

PHOTOSYNTHESIS UNDER FIELD CONDITIONS: RADIANT ENERGY EXCHANGES WITHIN A CORN CROP CANOPY AND IMPLICATIONS IN WATER USE EFFICIENCY

DA TASK 3A99-27-005-08

by

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under

USAEPG Cross Service Nr 2-62

for

Meteorology Department
U. S. Army Electronic Proving Ground
Fort Huachuca, Arizona

July 1962

SUMMARY

DA TASK: 3A99-27-005-08, Micrometeorology (USAEPG)

TITLE: Photosynthesis Under Field Conditions: Radiant Energy Exchanges Within a Corn Crop Canopy and Implications in Water Use Efficiency.

ORIGINATOR: Northeast Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, Ithaca, New York

Data are reported from net radiation measurements at various heights in a dense crop of corn. One net radiometer was mounted at a height of 420 cm, about 120 cm above the top of the corn plants. Net radiation measurements at selected levels in the canopy were taken with a mobile radiometer as it moved along a 100-foot course between two corn rows. Transmission data obtained for the respective heights with a Miller field light transmission photometer indicate that shortwave transmission can be expressed as an exponential function of height, as well as of cumulative leaf area index. To a first approximation, net thermal radiation was an exponential function of height except at lower levels and at the top of the crop.

A photosynthetic efficiency of 6.84 percent was obtained from calculations using data for radiation absorbed vs plant dry matter produced. Potential transpiration by "crop layers" was calculated. On a daily energy basis, the potential transpiration/potential photosynthesis ratio was 16. Soil water evaporation was calculated and it was estimated that it could constitute 17 percent of the total evapotranspiration.

Meteorology Department
U. S. Army Electronic Proving Ground

PHOTOSYNTHESIS UNDER FIELD CONDITIONS. IX. Radiant energy exchanges within a corn crop canopy and implications in water use efficiency[1]

by

L.H. Allen, C.S. Yocum, and E.R. Lemon[2]

SYNOPSIS

Data are assembled giving sinks of shortwave radiation within a corn crop canopy. From these data, and from net radiation measurements obtained at 225, 175, 100, and 20 cm. within a crop of corn 300 cm. high, net thermal radiation is calculated at those respective heights. Transmission data at those heights, using a Miller field light transmission photometer, indicate that shortwave transmission can be expressed as an exponential function of height as well as of cumulative leaf area index. To a first approximation, net thermal radiation has an exponential distribution except at lower depths and at the top of the crop. Anomalies in net thermal radiation profiles are tentatively attributed to leaf and row orientation. Evaporation, photosynthesis, and $\frac{\text{evaporation}}{\text{photosynthesis}}$ are calculated.

[1] Contribution from the Northeast Branch of the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, cooperating with the N.Y.S. Agr. Exp. Station at Cornell University. The work was supported in part by the Meteorology Dept., U.S. Army Electronic Proving Ground, Fort Huachuca, Arizona. Dept. of Agronomy Series Paper No. 582. Special thanks go to Dr. Edward E.Miller, Dept. of Physics, Univ. of Wisconsin for his advice on radiation measurements in the field; to Dr. C.B. Tanner, Dept. of Soils, Univ. of Wisconsin, for the use of his Miller field light transmission photometer; and to Dr. L.J. Fritschen, Agricultural Research Service, USDA, Tempe, Ariz., for the use of two of his hemispherically shielded net radiometers.

[2] Soil Scientist, USDA, Ithaca, N.Y.; formerly Assistant Professor in Botany, Cornell Univ. and Plant Physiologist, USDA, now Associate Professor in Botany, Univ. of Michigan, Ann Arbor; and Soil Scientist, USDA and Associate Professor in Agronomy, Cornell Univ., Ithaca, N.Y., respectively.

I. INTRODUCTION

Much work has been done (theoretical and experimental) on specific aspects of radiant energy distribution within crop canopies (2, 8, 10, 13, 14, 15). Denmead, Shaw, and Fritschen (2) have recently reported on the vertical and horizontal distribution of net radiation within a crop of hill-planted corn. From their data they drew iso-radiative flux lines at two levels within the corn canopy. Also, they compare the fraction of net radiation being absorbed by the soil with the portion of evapotranspiration due to direct evaporation from the soil.

Zenbei Uchijima (14) has studied theoretically the distribution of radiation within a rice paddy. He divides the radiation into three components; shortwave direct; shortwave diffuse; and long wave (thermal.) From these he arrives at an equation for net radiation at any level within the crop. The following discussion will handle the problem in a less elaborate fashion.

Reflectivities of various plant communities and isolated individual leaves have been investigated by workers of various backgrounds. These investigations, however, have not dealt with conditions within the plant canopy. Also, leaf transmission information is lacking outside the visible range, especially by spectral distribution.

Monteith (8) reports an average reflectivity of short wavelength radiation over short grass of 0.25 at Kew (England). For soil, he found reflectivity values ranging from 0.11 at field capacity to 0.18 after several days with no rain. In studying sugar beets, low reflectivities (0.14) were observed during the stage of growth when the leaves were upright. Monteith suggested that these low reflectivities were due to an incomplete ground cover. The highest reflectivity, 0.26, was noted at the end of July, after which the reflectivity began to drop to 0.22 as the sugar beets became more mature. Monteith attributed the drop to the radiation being "trapped" by multiple reflections. Our fullgrown dense corn crop at

Ellis Hollow (Ithaca, N. Y.) was observed to have a lower reflectivity than Monteith's sugar beets or short grasses. The reflectivity (0.3 - 3.0μ) as measured with upright and inverted Eppley pyrheliometers had a considerable range, but 0.17 was an average obtained by us from several days of continuously recorded data. Perhaps Monteith's idea of "trapped" radiation applies here and/or our crop of corn may have had an inherently low reflectivity.

Billings and Morris (1) did work on individual leaf reflectivities in the range of 0.4 - 1.1μ, using plants from various ecological environments. In general, except for deserts and subalpine slopes, they found reflectivities of the order of 5% in the blue and in the red, with a peak of about 15% in the green, and reflectivities greater than 50% in the near infra-red out to 1.1μ.

Gates and Tantraporn (4) did a study of the reflectivity of deciduous tree leaves and herbaceous plant leaves in the infra-red out to 25μ. They found that the high values for reflectivity in the near infra-red, beginning at 0.7μ had dropped before reaching 3μ. The reflectivities from 3 - 25μ were usually roughly the same for a given species, but increas~~ing~~ed toward the less energetic end of the spectrum. There was quite a range in reflectivity among the various species checked in this span of wavelength, ranging from nil up to over 10% at certain wavelengths.

Very little information is in the literature about leaf transmission in the infrared. Work of Rabideau, French, and Holt (9) and Yocum, Allen, and Lemon (15), showed high transmission out as far as 0.90μ. At 0.8μ, the ~~later~~ latter authors found about 50% transmission. Gates and Tantraporn (4) reported that transmissivity of leaves was zero beyond 1.0μ, but some information collected by us indicates considerable transmission out to 2.0μ. Unfortunately, the method of measurement (using a Beckman DU spectrophotometer) did not account for scattered light so the data are qualitative only. A slight decrease in transmission was observed from 0.7 to 2.0μ. The actual transmission (and reflection) should be determined in an Ulbricht sphere. Such information would be helpful in determining the fate of various portions of incoming radiation within the plant cover.

Many studies have been done recently relating evapotranspiration to net radiation (2, 5, 6, 10, 12, 13.) Most of these studies consider the problem of evapotranspiration from the whole crop, with little attention to what is going on within the crop itself. However, Saito (10) has figures illustrating that around the noon hour transpiration accounted for most of the net radiation absorbed in the upper layer of wheat plant cover, and for a large part of the net radiation absorbed in the middle layer. Graham and King (6) working with corn at Guelph, Ontario, also found that evapotranspiration accounted for a large percent (81 ±9%) of net radiation when both the experimental site and surrounding area ~~was~~ were moist. In this paper, as a first approximation, transpiration and soil evaporation will be considered equivalent to the net radiation absorbed by layers of corn crop cover and by the soil.

Workers dealing with water use in corn have determined the portion of evapotranspiration due to evaporation from the soil. Tanner, Peterson, and Love (13), in experiments with drilled and check hill-planted corn, found soil evaporation/evapotranspiration ratios ranging from 0.25 to 0.50, depending upon the type of planting and the density of the stand. Check rows tended to allow more radiation to penetrate, and hence higher net radiation near the ground. Denmead, Fritschen, and Shaw (2), working with 40-inch spaced, hill-dropped corn with a density of 16,000 plants per acre, reported 42% of the net radiation above the crop reached the ground when the corn had a leaf area index of 2.50. Later, the value dropped to 22% at a leaf area index of 2.84. These workers found also in later season corn that 73% absorption of radiation with the crop corresponded to transpiration being 75% of evapotranspiration, based upon calculations from black plastic covered plots.

Table 1. Incident shortwave radiation, net radiation, and net thermal radiation in Ellis Hollow corn.
September 10, 1961

Time	Inci. rad.1/	Rn(gm-cal/cm²/min.) Height (cm.) 265	225	175	100	20	Tn(gm-cal/cm²/min.) Height (cm.) 265	225	175	100	20
1230	1.11	0.768	0.604	0.540	0.216	0.166	0.153	0.076	-0.086	0.049	-0.022
1245	1.09	.768	.647	.349	.178	.199	.137	.027	.109	.083	-0.057
1300	1.06	.705	.469	.335	.207	.139	.175	.081	.110	.046	-0.001
1315	1.05	.705	.522	.388	.226	.134	.167	.122	.053	.025	.003
1330	1.02	.680	.388	.238	.175	.128	.167	.237	.190	.069	.005
1345	.98	.642	.336	.286	.218	.166	.172	.264	.125	.016	.039
1400	.95	.629	.418	.265	.142	.096	.159	.164	.134	.085	.027
1415	.89	.573	.254	.227	.128	.118	.166	.291	.147	.085	-0.002
1430	.85	.522	.323	.288	.131	.088	.183	.198	.069	.072	.028
1445	.79	.472	.438	.226	.116	.079	.183	.046	.106	.073	.024
1500	.72	.434	.277	.231	.126	.072	.163	.164	.071	.046	.022
1515	.66	.378	.180	.158	.086	.074	.170	.225	.119	.072	.012
1530	.63	.346	.218	.182	.090	.066	.177	.168	.083	.060	.016
1545	.57	.296	.141	.139	.064	.061	.177	.208	.100	.072	.013
1600	.50	.233	.120	.121	.060	.047	.182	.186	.089	.060	.018
1615	.44	.176	.089	.089	.051	.040	.189	.181	.096	.054	.017
1630	.37	.126	.047	.073	.042	.038	.181	.180	.082	.046	.010
1645	.29	.063	.039	.044	.035	.034	.178	.139	.053	.034	-0.001
1700	.23	.031	.028	.025	.031	.025	.160	.113	.072	.024	.005
1730	.10	-0.038	.038	.038	.038	.038	.121	.023	.004	-0.004	-0.014
1745	.05	-0.044	.031	.031	.038	.038	.086	.000	-0.010	-0.026	-0.031
1800	.02	-0.050	-0.019	-0.013	-0.006	.000	.067	.031	.021	.011	.003
1815	0.00	-0.050	-0.025	-0.019	-0.006	0.000	.050	.025	.019	.006	0.000
		A v e r a g e					0.171	0.166	0.100	0.057	0.006

1/ Incident radiation (gm-cal per cm² per min.)

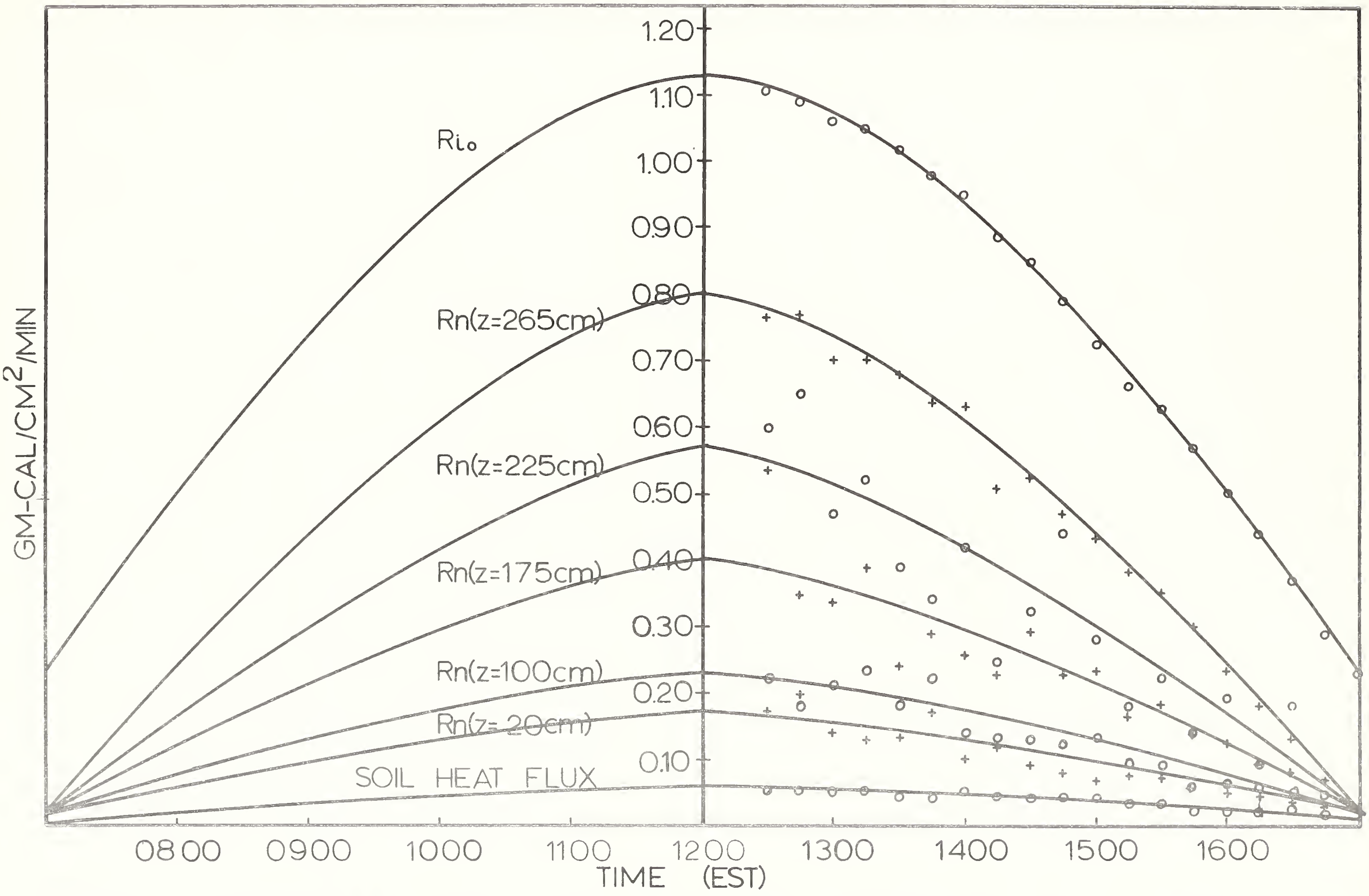

FIGURE 2 – INCIDENT SHORTWAVE RADIATION (Ri_o) AND NET RADIATION ($Rn(z)$) AT VARIOUS LEVELS WITHIN A CORN CROP CANOPY

continuous fit to the data. The afternoon data were assumed to be valid for the morning also. Incident shortwave data for the afternoon of September 10 is also recorded in figure 2, as well as soil heat flux. The incident shortwave data were also available for the morning. These data, not plotted here, indicated that an extrapolation of the curves back through the morning hours, symmetric about the noon hour, would be quite valid.

In order to apportion the net radiation into various components - visible (0.4 - 0.7 μ), solar infrared or near infrared (0.7 - 3.0 μ); and thermal infrared or far infrared ($>$ 3.0 μ), additional data were collected with other instruments. Incident shortwave radiation (0.3 μ - 3.0 μ) was determined at each 15-minute interval from an Eppley pyrheliometer at 200 cm. above the crop. Percentage of shortwave reflected radiation obtained from this unit, and from a shielded inverted pyrheliometer, was averaged for several days and 17% reflection was obtained.

From work in the same corn crop with a grating spectrophotometer, Yocum et al (15), found 7% transmission (0.4 - 0.7 μ) on August 20, 1961, at 0910 EST. This day was foggy, and the radiation quite diffuse. This type day should give a good overall picture of visible radiation transmission through the crop. On this day, it was found that 53% of the incident shortwave radiation falling on the crop was in the visible (0.4 - 0.7 μ) range, leaving 47%, most of which was in the near infrared region. (these data are not presented in that paper)

Reflection from a similar corn crop in the visible region was found to be 7% by Yocum et al (15) in 1960. Since roughly 50% of the incident shortwave radiation falling on a crop is in the visible range, this means about 3.5% of the total incoming shortwave radiation was reflected from the corn crop as visible radiation. With 17% of the total shortwave radiation being reflected by the corn crop, this leaves 13.5% of the incident shortwave radiation being reflected as near infrared radiation.

Likewise, for 7% of the visible radiation being transmitted as visible radiation through the corn crop, we have 3.5% of the total shortwave radiation falling upon the crop transmitted through the crop.

Since no really satisfactory data were available for either total shortwave (0.3 - 3.0 μ) transmission through the crop, or shortwave infrared transmission (0.7 - 3.0 μ), an approximation was made. On the basis of leaf transmission measurements made with a Beckman DU spectrophotometer, and the Yocum et al (15) data available in the wavelength range 0.7 - 0.9 μ in corn, an estimated 20% of the shortwave infrared radiation would be transmitted, or reach the ground by multiple reflection. Or, an estimated 10% of the total incident shortwave radiation was transmitted as near infrared radiation.

Summing the transmitted visible and the transmitted infrared radiation gave 13.5% transmission. This figure was used in later calculations to obtain thermal radiation within the plant canopy. The shortwave radiation sinks are tabulated in table 2.

Percentage light transmission measurements (0.4 - 0.9 μ) at 225, 175, 100, and 20-cm. heights within the corn canopy were taken on August 30, 1961, using the Miller light integrating instrument (7). Several measurements were made at each height four times during the day. Measurements for each particular time and height were averaged (table 3). Data in table 3 and figures 3-A and 3-B show that transmission was highest during the noon hour, and remained rather constant at other periods during the day. When transmission was plotted on a log scale vs. the height above ground on a linear scale, the data could be fitted to a straight line, indicating a reasonable fit to Beer's law. (figure 3-A). The actual average height to the maximum height of the top leaf of each plant measured was 266 cm. Since the linear plot of log (transmission) vs. height tends to intercept the 100% transmission level at about 265 cm., this height may be considered the "effective" height of the corn plant, as far as light transmission measurements are concerned.

Table 2. Sinks for shortwave radiation within corn canopy.

	Incident shortwave	Visible component	NIR component
	%	%	%
Reflected	17.0	3.5	13.5
Transmitted	13.5	3.5	10.0
Absorbed	69.5	46.0	23.5
	100.0	53.0	47.0

Table 3. Percent transmission of light through the corn crop canopy Ellis Hollow, Ithaca, N.Y., Aug. 30, 1961[1/]

(EST)	Ave. Height cm.	Average (% transmission)
0930	20	5.7
0950	100	13.0
1000	175	33.8
1015	225	84.0
1200	20	12.6
1215	100	20.7
1225	175	38.3
1235	225	84.0
1350	20	6.7
1405	100	12.9
1420	175	31.4
1430	225	69.2
1545	20	7.4
1600	100	14.2
1608	175	33.1
1620	225	67.6
Average	20	8.1
	100	15.2
	175	34.2
	225	76.2

[1/] Data obtained on down-row measurements in 29-inch rows with a Miller light integrating photometer.

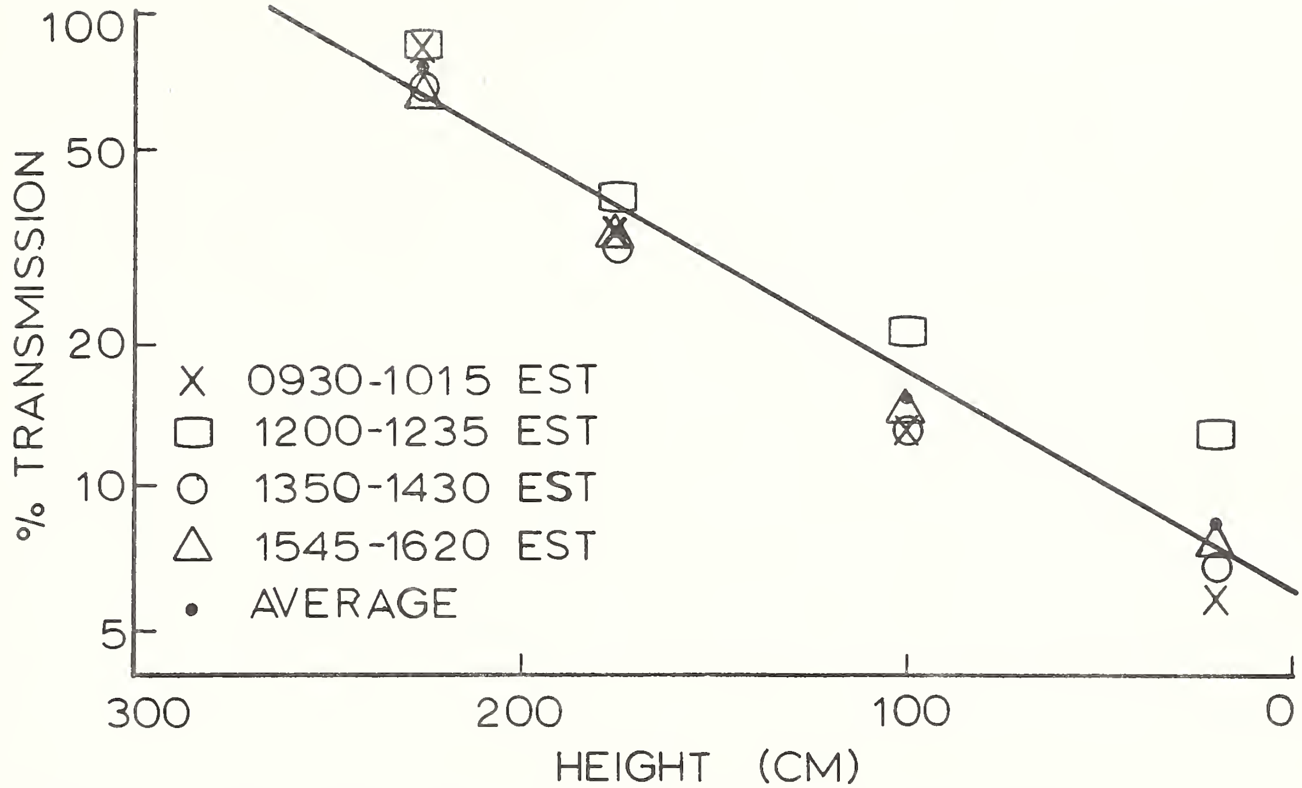

FIGURE 3-A—MILLER PHOTOMETER TRANSMISSION MEASUREMENTS IN THE CORN CANOPY

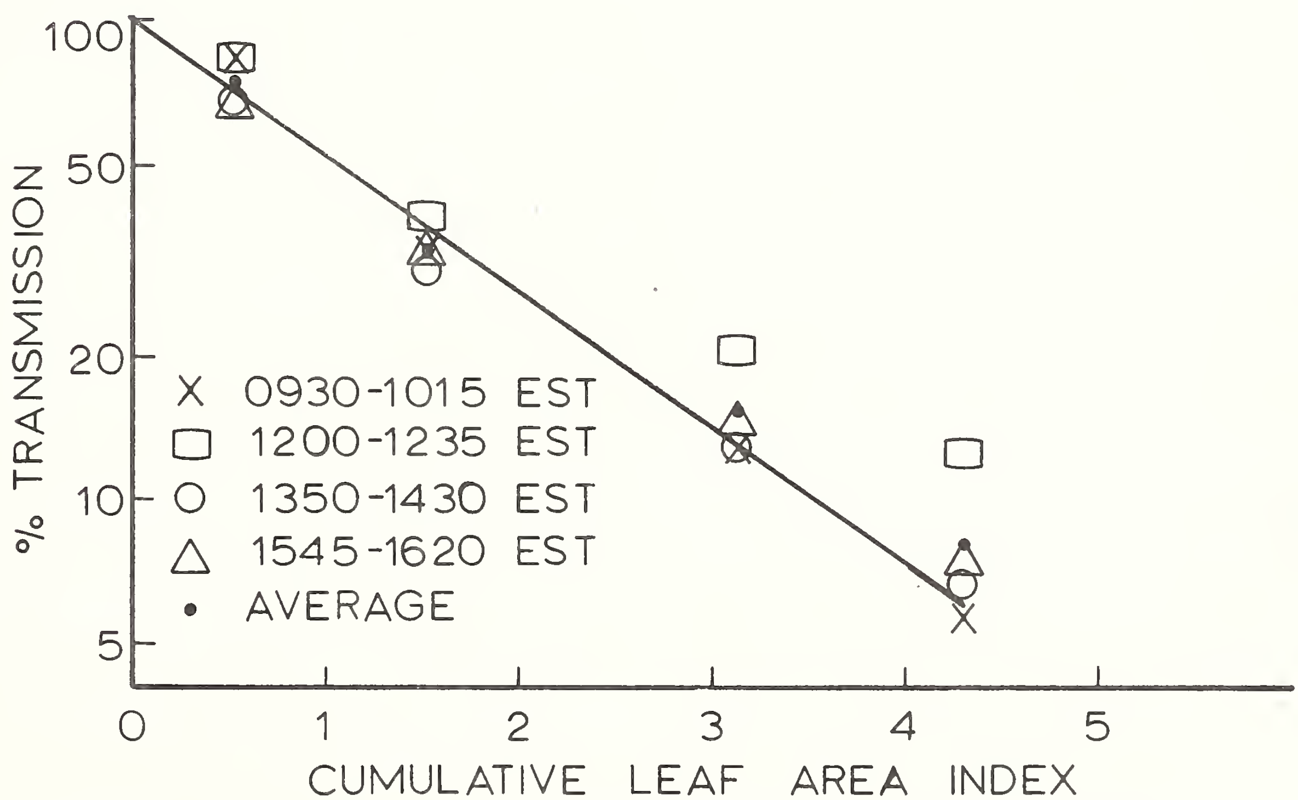

FIGURE 3-B—MILLER PHOTOMETER TRANSMISSION MEASUREMENTS IN THE CORN CANOPY

It was expected that light transmission would be more closely related to cumulative leaf area index than to the height of the corn crop. So measurements relating to cumulative leaf area index to height were made. A comparison of figure 3-A and 3-B indicates that cumulative leaf area index gives a somewhat better fit to Beer's law absorption than does height of crop.

The leaf area index was obtained as follows: On September 7, 1961, a 10-foot length of 29-inch row was chosen in the Ellis Hollow corn field. No particular method was used in choosing this particular sample, other than it "looked"like a normal, representative sample, and was located in the same area ~~when~~ where light transmission measurements were taken. Fifteen plants were contained in this 10-foot length. Since the rows were 29 inches apart, the following expression gives the number of plants per acre.

$$\frac{15 \text{ plants} \times 43{,}560 \text{ sq.ft/acre}}{(10 \times \frac{29}{12}) \text{ sq. ft.}} = 27{,}000 \text{ plants/acre}$$

The average height was 302 cm. Leaf area index was determined for layers within the corn crop. The boundaries of these layers were determined by the heights at which light transmission measurements were made by the Miller light integrator. From the measurements, both LAI for each level, and cumulative LAI, were calculated. The LAI was computed two ways: i.e., in one measurement, suckers were included*, and in another they were excluded**. The results are tabulated in table 4.

Upon plotting these data, the cumulative LAI showed a close approximation to a sinusoidal curve (figure 4). The following equation can be used to describe the cumulative LAI.

$$L = k - A \cos \theta \qquad [1]$$

where: L = cumulative leaf area index

k, A = constants

θ = value related to depth within the plant canopy

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* and ** See table 4.

Table 4. LAI and cumulative LAI

Height interval (cm.)	LAI (suckers not included)**	LAI cumulative (suckers not included)**	LAI (suckers included)*	LAI cumulative (suckers included)*
300 - 225	0.53	0.53	0.53	0.53
225 - 172	0.99	1.52	0.99	1.52
175 - 100	1.61	3.13	1.61	3.13
100 - 20	0.83	3.95	1.17	4.30
20 - 0	∼ 0	3.95	∼ 0	4.30

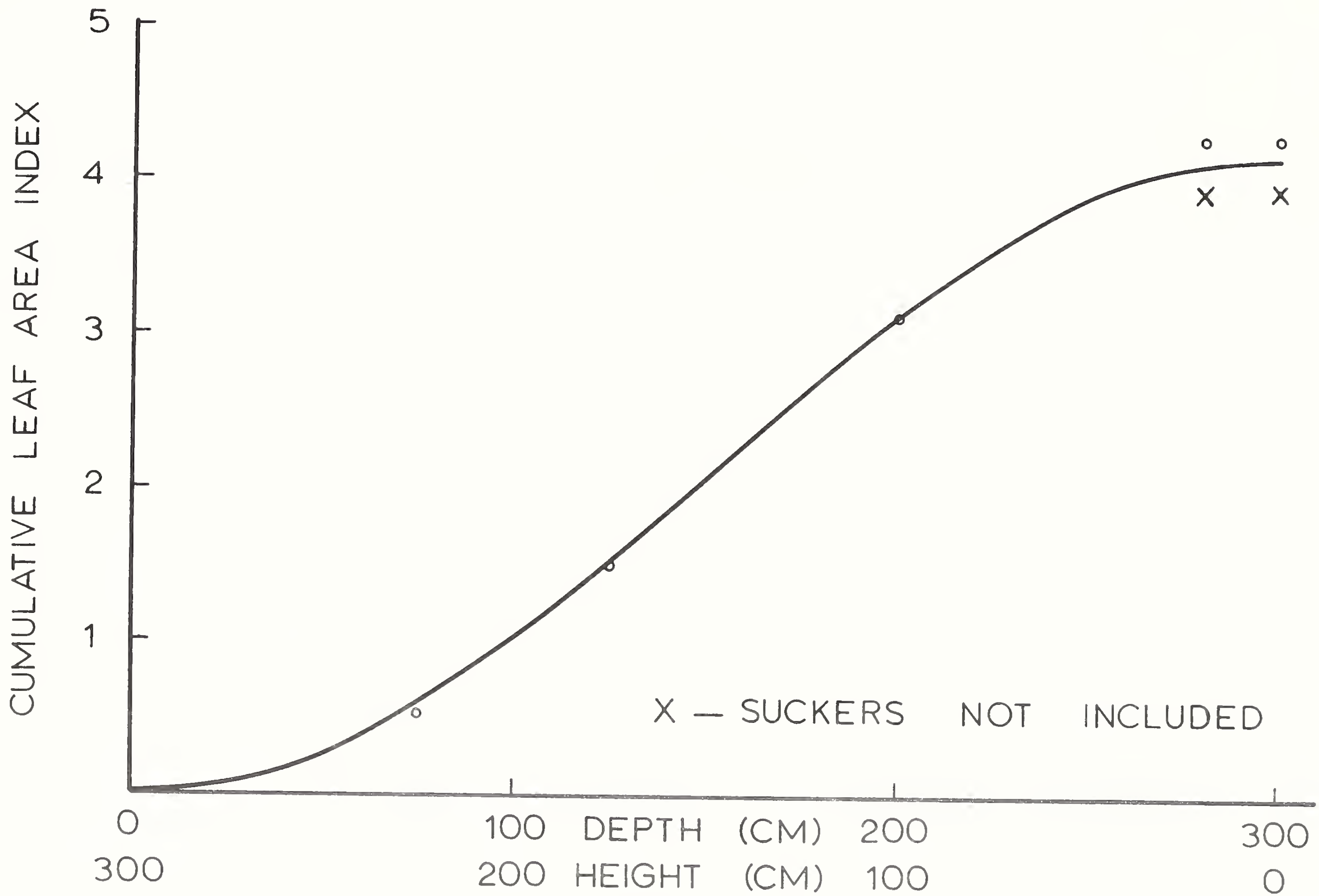

FIGURE 4—RELATIONSHIP BETWEEN CUMULATIVE LEAF AREA INDEX AND HEIGHT OF MATURE CORN

If we chose $k = 2.10$

$$A = 2.10$$

$$\theta = x \left(\frac{d\,\theta}{d\,x}\right) \qquad [2a]$$

where x = depth within the crop,

$$\theta = x \frac{2\pi}{300} \qquad [2b]$$

$$L = 2.10 \left[1 - \cos\left(\frac{\pi x}{300}\right)\right] \qquad [3a]$$

which is applicable for:

$$x = \begin{cases} 0 & \text{when} \quad x < 0 \\ x & \text{when} \quad 0 < x < 300 \\ 0 & \text{when} \quad x > 300 \end{cases}$$

To express L as a function of height, recall that $x = 300 - z$, where 300 = total height; z = height; and x = depth.

$$\text{Then } L = 2.10 \left[1 - \cos\left\{\left(\frac{\pi}{300}\right)(300 - z)\right\}\right] \qquad [3b]$$

$$= 2.10 \left[1 - \cos\left(\pi = \frac{z\pi}{300}\right)\right] \qquad [3c]$$

$$L = 2.10 \left[1 - \cos \frac{z\pi}{300}\right] \qquad [3d]$$

where:

$$z = \begin{cases} 0 & \text{where} \quad z < 0 \\ z & \text{where} \quad 0 < z < 300 \\ 0 & \text{where} \quad z > 300 \end{cases}$$

It also is probable that the data could be approximated by a curve of the form:

$$L = k + a_1 (h - h_o) + a_2 (h - h_o)^{1/3} \qquad [4]$$

where:

k, h_o, a_1, and a_2 are constants;

L = cumulative leaf area index

h = height of crop

Even though log (transmission) vs. cumulative leaf area index gives a better fit to Beer's law than log (transmission) vs. height (actually depth within crop), figure 3-A indicates that the latter representation is certainly useable. One reason a graph of this type works well is that the straight line plot is drawn to intercept the 100% transmission level at the "effective" height, rather than the absolute height of the corn plants. So calculations in this paper were based upon height rather than cumulative leaf area index. Height measurements are certainly more easily obtained than leaf area indices. As mentioned earlier, the height used is height to top of highest leaf, and not height to top of tassel.

Measurements with the Miller light integrator agree very well with the 7% transmission in the visible obtained by Yocum et al (15). One would at first think the Miller instrument would give significantly higher values, since its photocell is sensitive to 0.9μ (5), and Yocum's data show about 35% transmission from 0.7 - 0.9μ . But the response of the Miller instrument photocells drops rapidly in the 0.7 - 0.9μ range. Also, the scatter of points is wide at the 20-cm. height, ranging from 5 to 16% around noon-time, and from 5 to 9.5% at other times.

In the crop at some level z above the ground, the radiative energy balance is given by:

$$Rn(z) = \text{transmitted shortwave}\downarrow + \text{thermal}\downarrow - \text{reflected shortwave}\uparrow - \text{thermal}\uparrow \qquad [5]$$

or

$$(\text{thermal}\uparrow - \text{thermal}\downarrow) = R_i(z) - R_r(z) - R_n(z) \qquad [6]$$

$$Tn(z) = R_i(z) - R_r(z) - R_n(z). \qquad [7]$$

Where,

$Tn(z)$ = net thermal (positive sign indicates thermal radiation is upward at height z above ground)

$R_i(z)$ = shortwave transmitted at z

$R_r(z)$ = shortwave reflected at z

$R_n(z)$ = net radiation at z

From the Miller photometer transmission data, figure 3-A, it appears that the percent transmission in a thick crop is not really related with sun angle except at noon-time. Hence, the percent transmission will be considered constant throughout the time interval involved. We can assume that the increasing ratio of $\frac{\text{sky radiation}}{\text{sun radiation}}$ compensates to some extent for the decreasing sun angle. Then in applying equation [7] we assume:

(1) Beer's law is valid for transmission vs. height;

(2) There is no change in absorption with respect to sun angle;

(3) Reflectivity of soil is same as reflectivity of crop (r = 0.17)

(4) Reflected shortwave radiation is a constant percent of the incident shortwave radiation at height z $[0.17\ R_i(z)]$.

Now, total shortwave radiation $R_i(z)$ at height z above the ground in the crop is given by:

$$R_i(z) = R_{io}\, e^{-k(265-z)} \qquad [8]$$

where R_{io} is the total shortwave radiation falling on the crop, and k is the "extinction coefficient".

From equations [7] and [8] we have:

$$T_n(z) = \left[(R_{io} - R_r)\, e^{-k(265 - z)}\right] - R_n(z) \qquad [9]$$

where:

$T_n(z)$ = net thermal radiation at height z ,

R_r = reflected shortwave radiation = 17% ,

R_{io} = incident shortwave radiation incident above the crop .

Therefore,

$$T_n(z) = \left[(R_{io} - 0.17\ R_{io})\ e^{-k(265-z)} \right] - Rn(z) \qquad [10]$$

By applying the boundary condition $z = 0$, we can evaluate k at $z = 0$.

At $z = 0$,

$$\frac{R_i(z=0)}{R_{io}} = 0.135.$$

Since $\dfrac{R_i\ (z)}{R_{io}} = e^{-k(265-z)}$, and $0.135 = e^{-2}$,

then $\dfrac{R_i\ (z=0)}{R_{io}} = e^{-265k} = e^{-2}$,

therefore, $k = \dfrac{2}{265} = 0.00754.$

III. INTERPRETATION OF RESULTS

A. Net Thermal Radiation

After the energy within the corn canopy was partitioned into incoming shortwave, reflected shortwave, and net radiation, the thermal energy exchanges were calculated. Thermal radiation flux within the corn crop is given as a function of height and time in table 1 and figures 5-A through 5-F. Both positive and negative values for thermal net radiation occurred. Positive values indicate a net flux upward; negative values, a net flux downward.

One apparent anomaly is immediately noticed in the noon-time net thermal radiation profile. At 1230 hours, the profile of net thermal radiation differs drastically from other times in the afternoon. This large deviation can be accounted for by considering:

(1) the equation from which the thermal radiative flux was calculated;

(2) the orientation of the corn rows;

(3) the "absorbing" shape of the corn plant (the vertical distribution of leaf surfaces); and,

(4) the time at which the differing profile occurs.

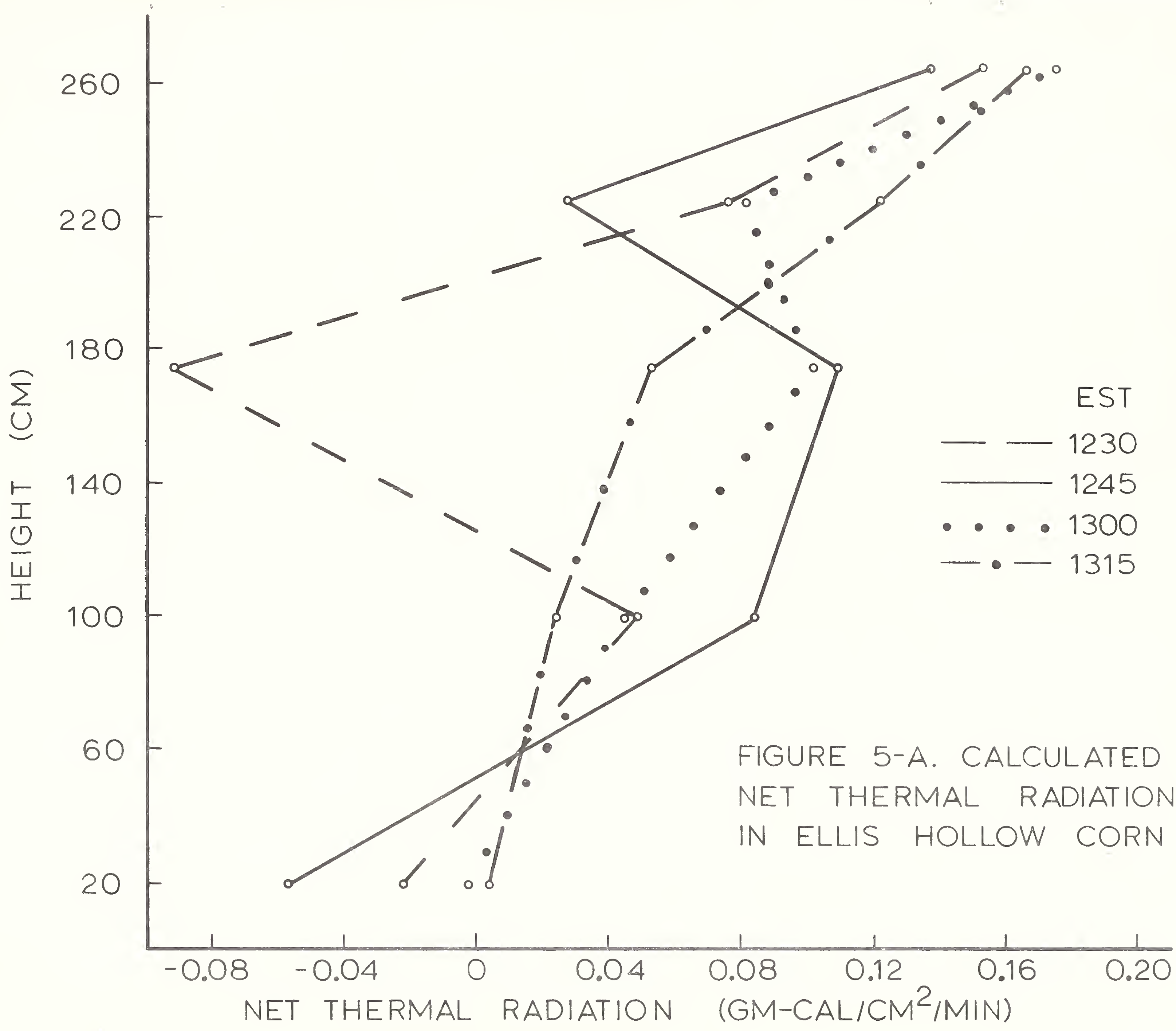

FIGURE 5-A. CALCULATED NET THERMAL RADIATION IN ELLIS HOLLOW CORN

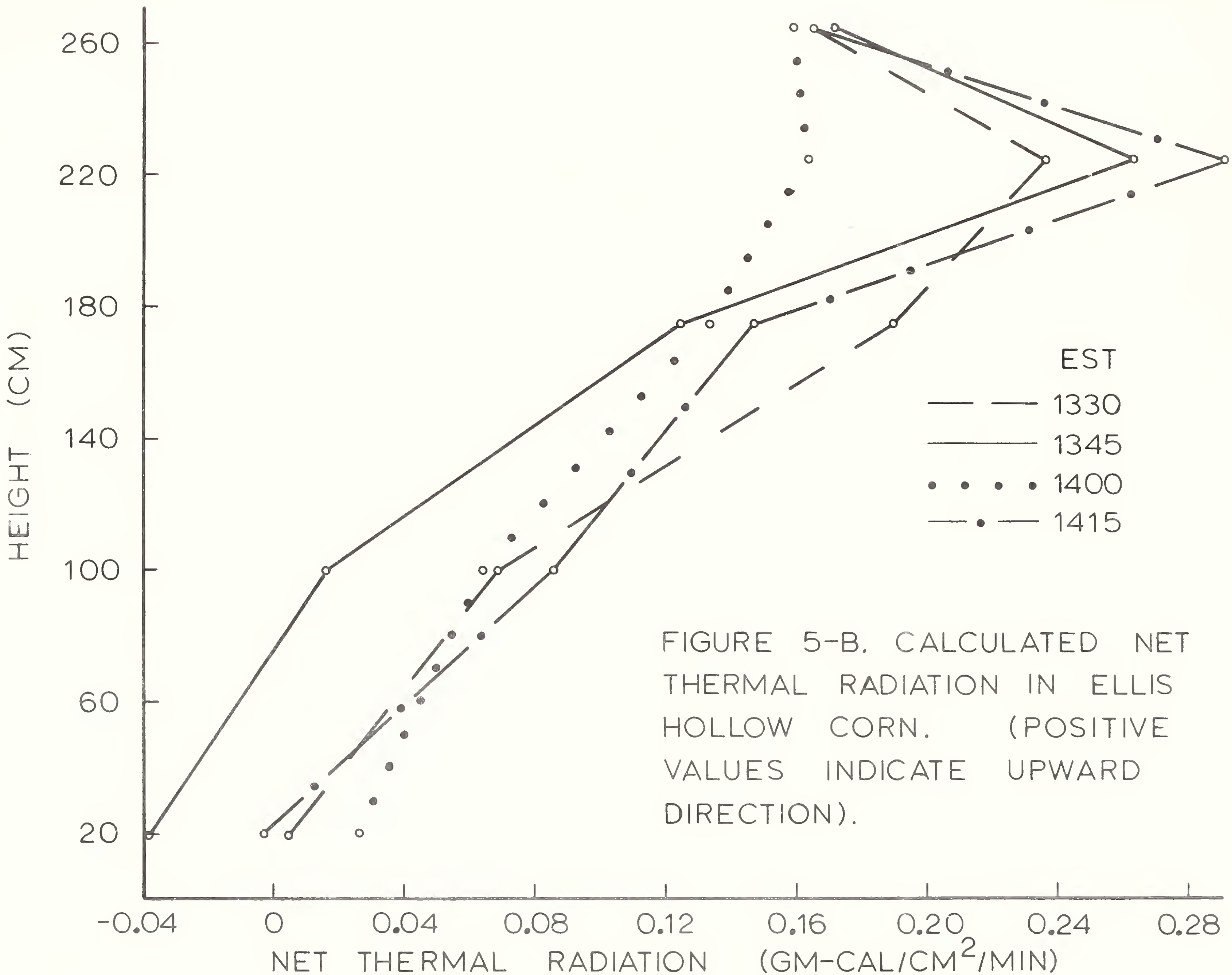

FIGURE 5-B. CALCULATED NET THERMAL RADIATION IN ELLIS HOLLOW CORN. (POSITIVE VALUES INDICATE UPWARD DIRECTION).

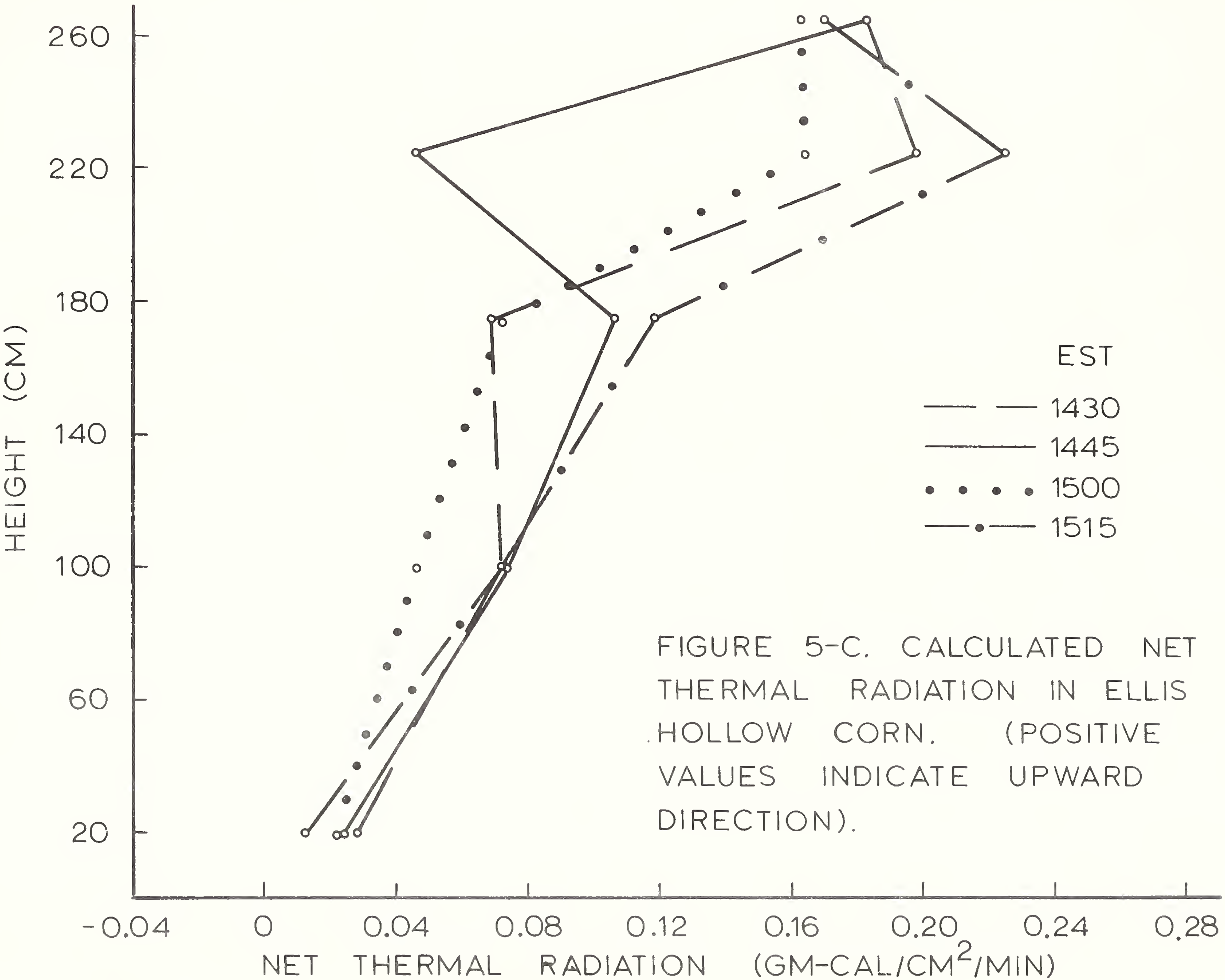

FIGURE 5-C. CALCULATED NET THERMAL RADIATION IN ELLIS HOLLOW CORN. (POSITIVE VALUES INDICATE UPWARD DIRECTION).

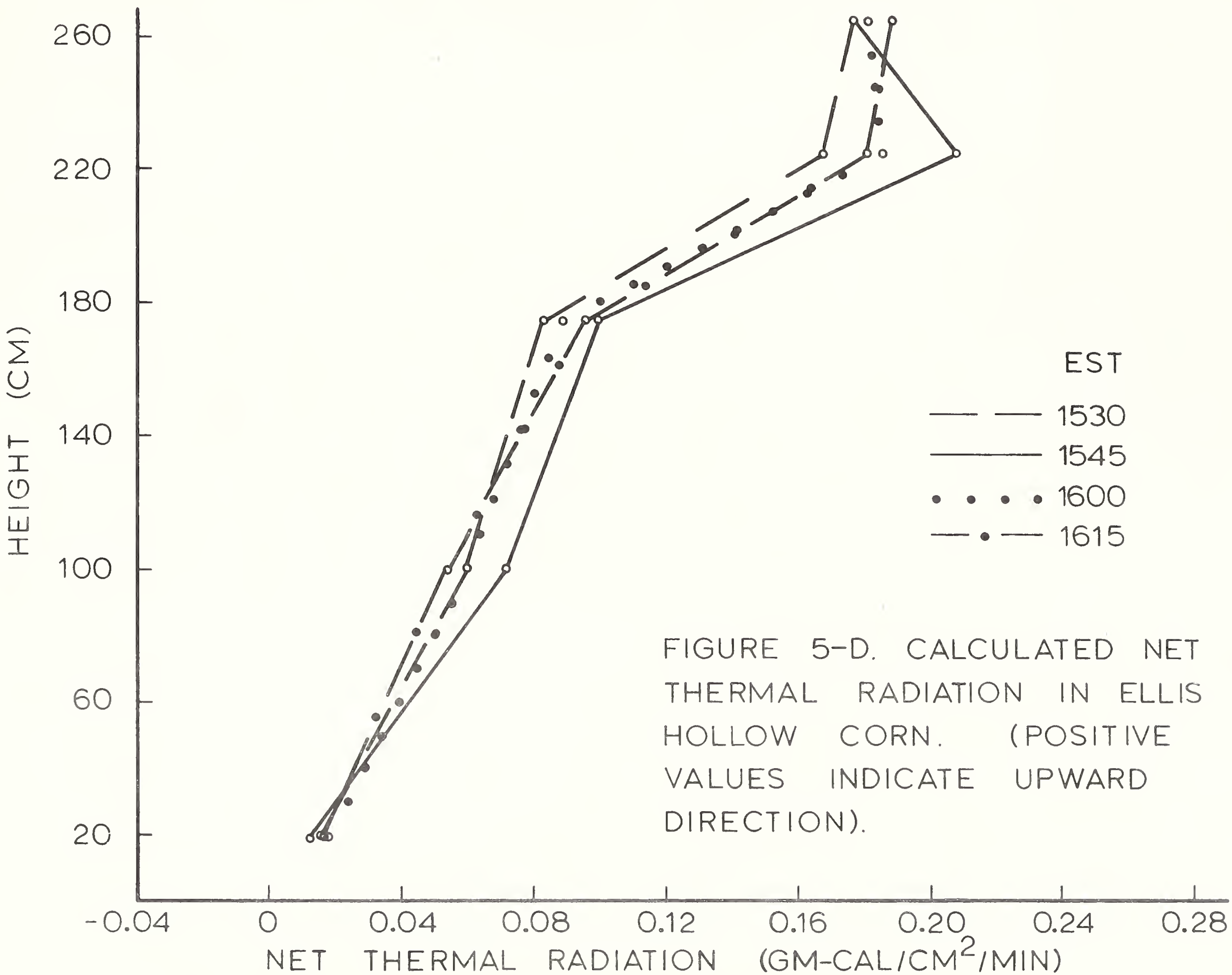

FIGURE 5-D. CALCULATED NET THERMAL RADIATION IN ELLIS HOLLOW CORN. (POSITIVE VALUES INDICATE UPWARD DIRECTION).

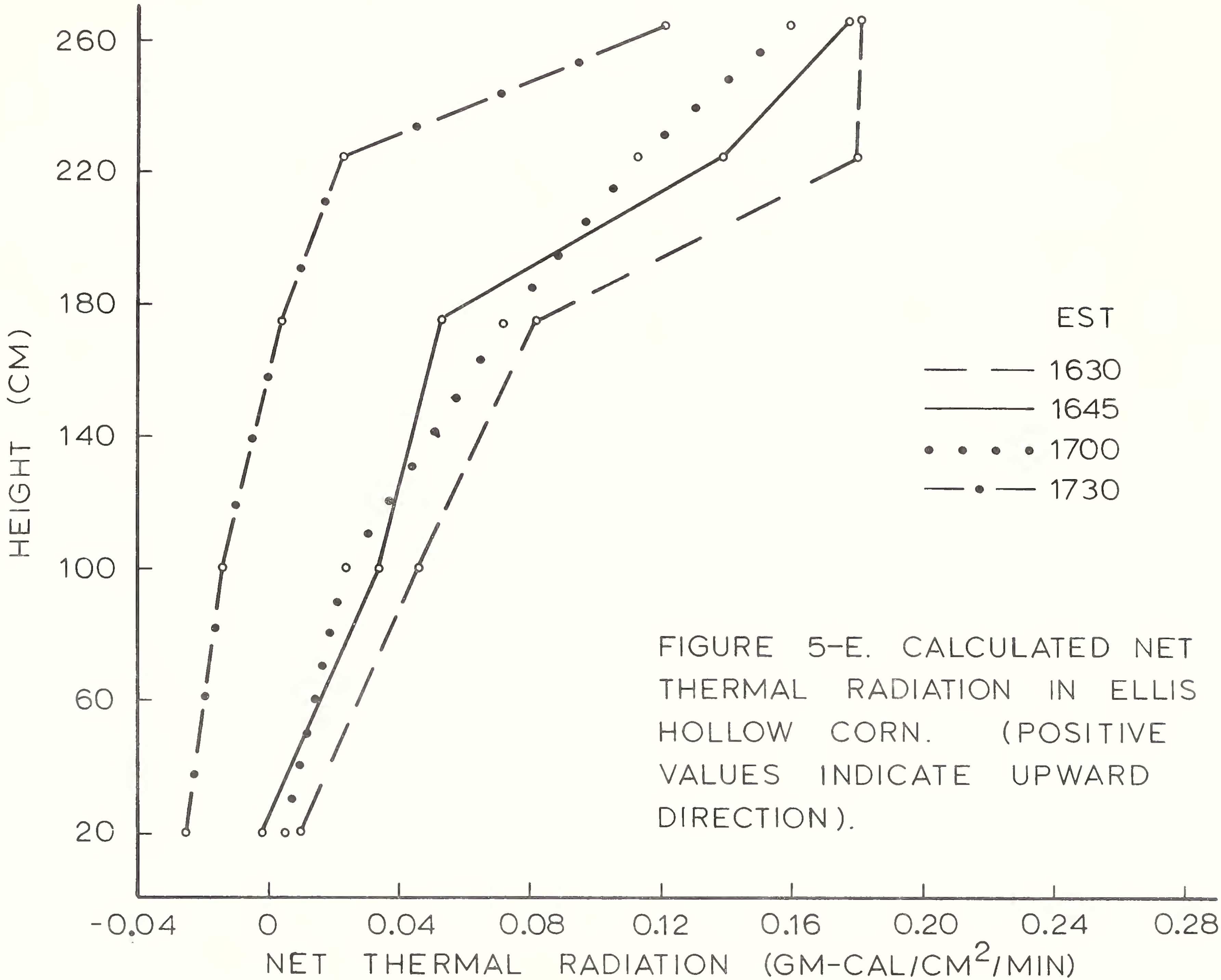

FIGURE 5-E. CALCULATED NET THERMAL RADIATION IN ELLIS HOLLOW CORN. (POSITIVE VALUES INDICATE UPWARD DIRECTION).

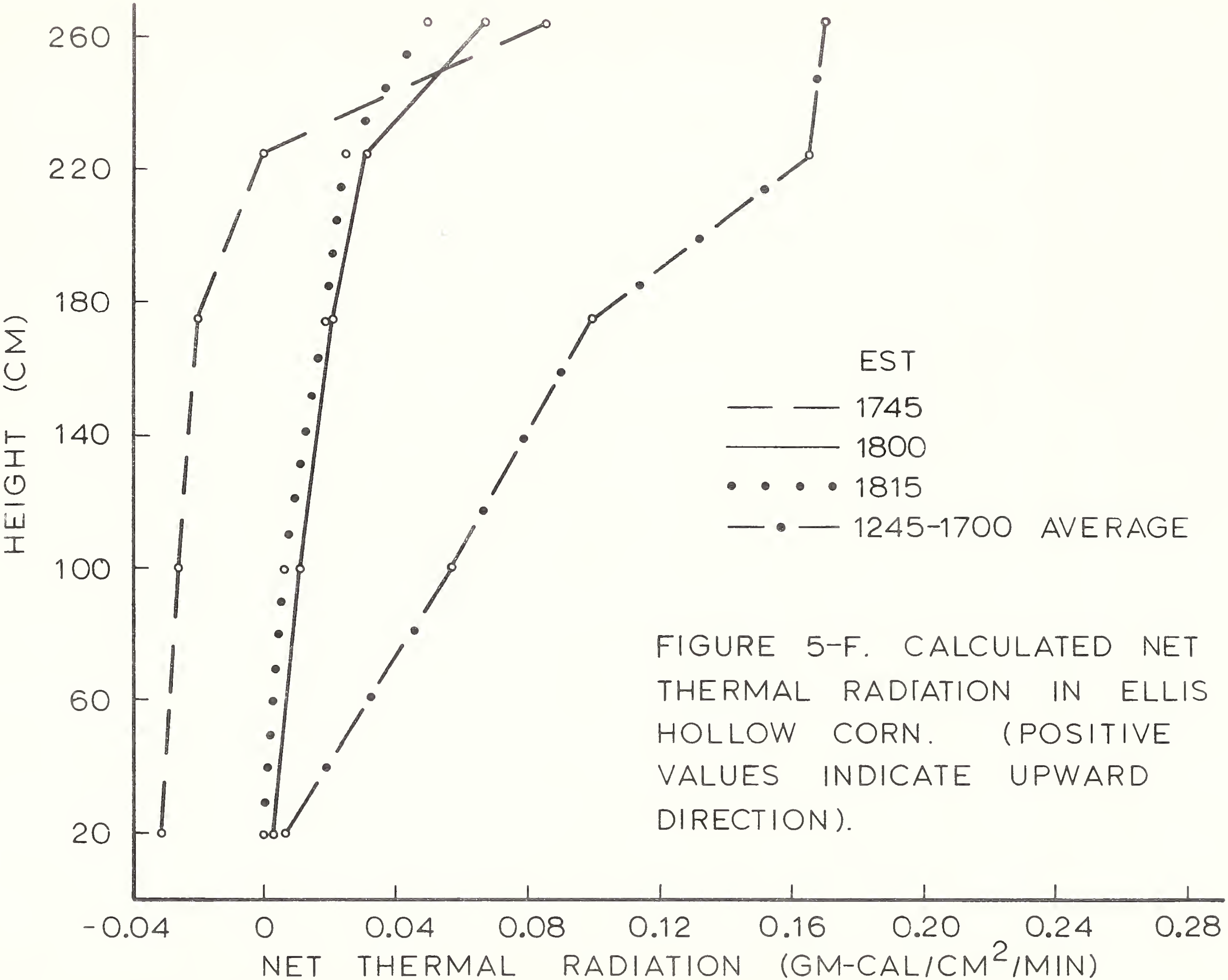

FIGURE 5-F. CALCULATED NET THERMAL RADIATION IN ELLIS HOLLOW CORN. (POSITIVE VALUES INDICATE UPWARD DIRECTION).

Reasonable leaf temperature differences between two given levels are too small to account for the large negative net thermal radiation measured at 175 cm.

In calculating net thermal radiation, we had:

$$T_n(z) = \left[(R_{io} - 0.17\ R_{io})\ e^{-k(265-z)} \right] - Rn(z) \qquad [10]$$

Thus, thermal radiation is calculated by difference rather than being obtained directly. This fact should be borne in mind in considering the results obtained for net thermal radiation.

The rows were oriented north-south. This, plus the vertical distribution of leaf surfaces, would cause more direct solar radiation to penetrate the crop during noon-time. Much more direct solar radiation could penetrate all the way down to the ground, but especially down through the first meter or so. The tassels and upper leaves would offer relatively less shade to the middle leaves at noon-time since they did not overlap as did the middle and lower leaves. Thus, there was a gap down between the individual plants in the rows, and between the rows, shown pictorially in figure 6.

Since the net radiation readings were made between the rows, the net radiometers received proportionately more radiation at noon-time than they would ordinarily receive, particularly at the higher levels in the crop. Thus, noon hour Rn measurements were high. However, this factor was not taken into account in the calculations, and the incident shortwave radiation was assumed to be attenuated and reflected as normally encountered for the rest of the day. Actually, it was being measured as downward shortwave radiation. Thus, the equation for T_n gave strongly negative results which are to be interpreted by the above explanation, and not as a very strong thermal flux downward.

The data for the other hours generally show positive values for thermal radiation throughout the profile. This fact, plus the fact that the thermal radiative flux values tend to increase in (positive) value up the profile, indicates a net thermal radiation back to the sky. At 265 cm. the calculated net thermal radiation (upward) averaged 0.17 gm-cal/cm^2/min. Values for all times were fairly

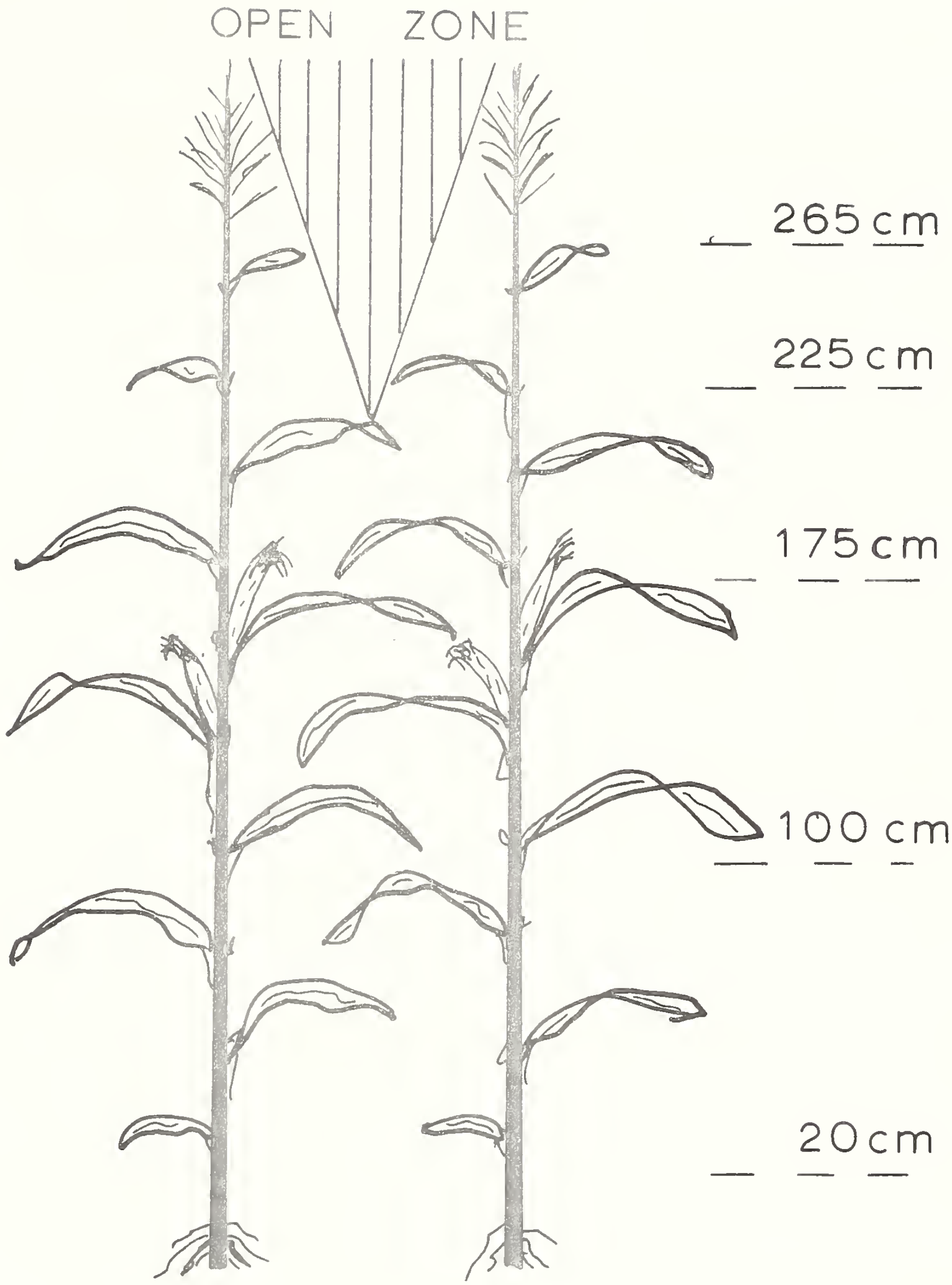

FIGURE 6

ILLUSTRATION OF PENETRATION OF SOLAR RADIATION BETWEEN NORTH-SOUTH ORIENTED ROWS AT SOLAR NOON

close to this value. This means that immediately above the crop, the effective sky temperature was about 20° C lower than the effective corn canopy temperature, assuming the temperatures are in the range where the black body emission (σT^4) changes at the rate of slightly less than 0.01 gm-cal/cm^2/min. per degree centigrade.

From the plot of the other net radiation profiles in figure 5, it is seen that the data are quite inconsistent at the 225-cm. level. The net radiation values vary quite a bit at other levels, too, but these variations do not change the basic shape of the curves obtained. An explanation for the widely varying values of net thermal radiation at the 225 cm. level may stem from the geometry of the corn crop--from the same factors discussed earlier. As the sun changes its altitude in the sky, there may be patterns of radiation penetration at the 225 cm. level which change, resulting in deviations from Beer's law absorption of incident radiation. These patterns would be related to the leaf arrangement of the individual plant, the orientation of rows, and the sun's altitude. Also, these patterns of radiation penetration could affect the resulting data indirectly as well as directly by causing wider differences in leaf temperature surrounding this 225 cm. level. Finally, turbulence will vary in the crop canopy, resulting in differences in leaf temperature.

After excluding the 1230-hrs. data, a "composite" curve was constructed by averaging data collected at each level from 1245 - 1700 hrs. EST. The results are found in table 1 and figure 5-F. The curve appeared to be somewhat like an exponential curve, so it was plotted on a semi-log basis (figure 7.) The resulting plot showed that under the conditions of these measurements and calculations, net thermal radiation had an exponential distribution within the crop except near the ground. Below 100 cm., the upward net thermal radiation decreased more rapidly than the empirical logarithmic plot of the data at higher levels within the crop. Under conditions where upward thermal radiation would be less than downward thermal radiation at some level within the crop, negative values would obtain, and an exponential relationship would not exist.

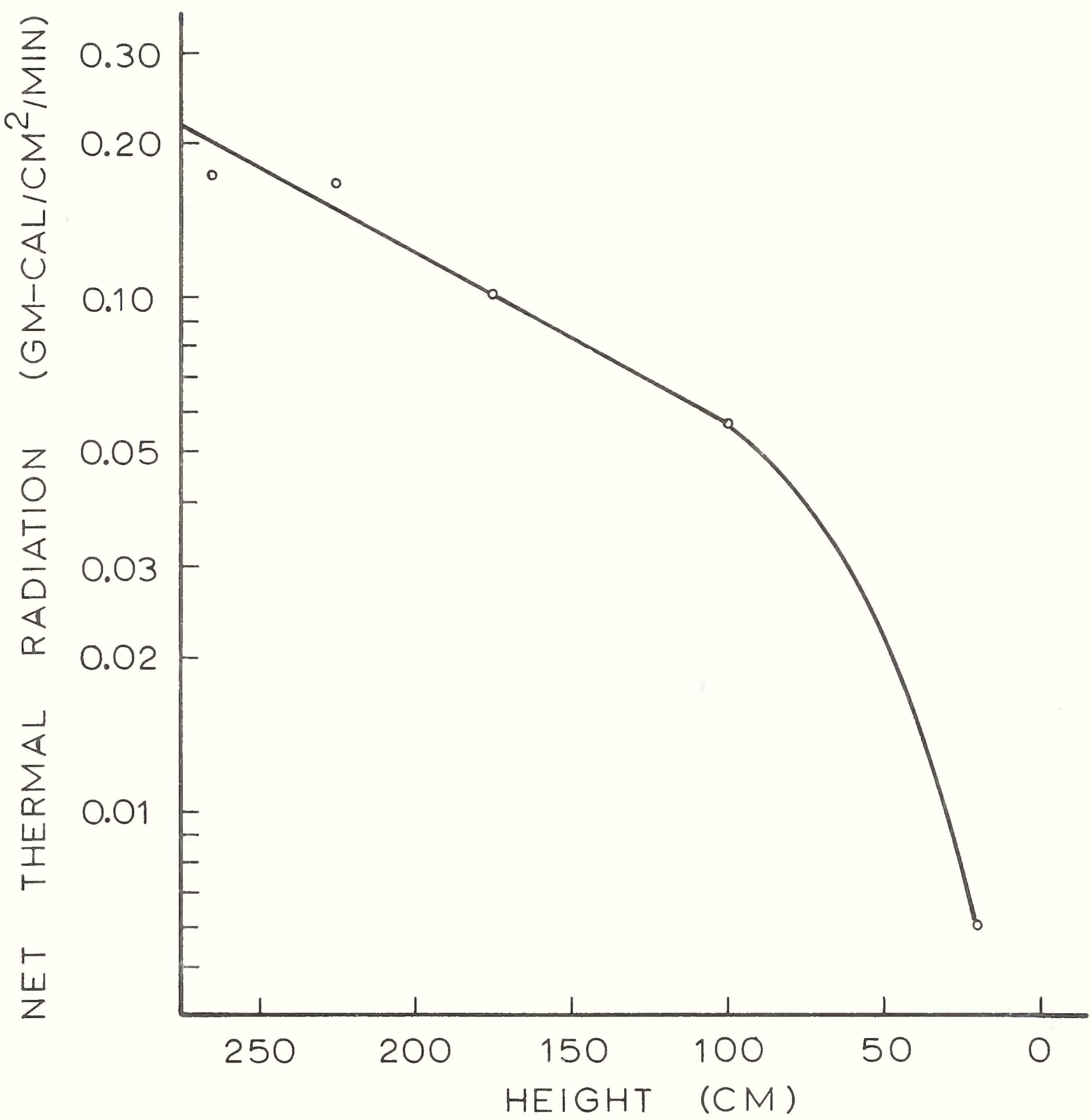

FIGURE 7—DEVIATION OF NET THERMAL RADIATION IN ELLIS HOLLOW CORN FROM AN EXPONENTIAL FUNCTION OF HEIGHT

After 1700 hrs., thermal radiation within the crop canopy began to change somewhat, as shown in table 1 and figures 5-E and 5-F. From 1700 hrs. to 1845 hrs. the net thermal radiation at the top of the crop dropped from 0.160 gm-cal/cm^2/min. to 0.050 gm-cal/cm^2/min. Two sets of data, at 1730 hrs. and 1745 hrs., gave noticeable negative values of net thermal radiation at the lower levels within the crop, indicating a downward flux. However, at the top of the crop, the net thermal flux remained positive. Apparently, the top of the crop was losing energy by radiation both upward and downward. By 1845 hrs., a positive upward radiation pattern throughout the canopy was obtained, except at 20 cm., where the net thermal radiation was zero.

By 1730 hrs., the incoming radiant energy supplied to the crop canopy was smaller than the calculated loss from the plant canopy due to thermal radiation. This discrepancy may be due to large relative errors in the recorded data, since at these times the instruments were giving only very slight deflections. Another explanation is that heat is being supplied from advected heat and/or condensing moisture.

B. <u>Water Use Efficiency</u>

With data available on radiation above the corn crop, and data on net radiation within the crop canopy, it is possible to make theoretical calculations on potential photosynthesis, potential evaporation and transpiration, and water use efficiency, layer by layer.

To calculate potential photosynthesis, the following conditions were used:

1. 7% transmission of visible radiation to the soil;
2. an exponential decrease of visible radiation with depth in the crop;
3. 7% reflection of visible radiation from the crop surface, with the reflectivity remaining constant throughout the crop;
4. 6.84% efficiency of photosynthesis from visible radiation. The above figure was obtained from harvested plant dry

4. cont.

matter data from July 19 to September 22, 1961, summarized by John Schafer and R.B. Musgrave [3]. Dry matter accumulation in corn plants including roots, plus a respiration term (assumed to be 25% of dry matter accumulation), was obtained. When converted to an energy basis, an average of 12.24 gm-cal/cm^2/day resulted. The average daily incident radiation (417 gm-cal/cm^2/day) was multiplied by 0.50 x 0.86, where 50% of the radiation was taken for the visible range, and 86% of the visible radiation was absorbed. This calculation gave 179 gm-cal/cm^2/day of absorbed visible radiation. Then the photosynthetic efficiency of absorbed visible radiation is:

$$12.24/179 = 0.0684, \text{ or } 6.84\%.$$

The net visible radiation at any level z is given by:

$$Vn(z) = (V_{io} - Vr)\, e^{-k(265-z)} \qquad [11]$$

where:

$V_{io} = (0.50)(R_{io})$ = the incident visible radiation above the crop

Vr = reflected visible radiation = 7% V_{io}, and $k = 0.0100$.

Using this expression, Vn(z) was calculated at 265, 225, 175, 100, and 20 cm., at 15-minute intervals from 1230 hrs. to 1700 hrs. Then the difference between the net visible radiation at the upper and lower boundaries of a given layer within the crop canopy gave the energy of the visible net radiation absorbed. Assuming a 6.84% efficiency of photosynthesis in the visible range, the photosynthesis rate in gm-cal/cm^2/min., for each layer within the crop canopy was calculated at each 15-minute interval. Also, the ratio of the photosynthesis rate to leaf area index was calculated. These calculations are summarized in table 5.

[3] Unpublished data.

Table 5. Potential photosynthesis (PS) and potential photosynthesis/leaf area index of Ellis Hollow corn, Sept. 10, 1961.[1/]

	Time	Height intervals - cm. 265 - 225	225 - 175	175 - 100	100 - 20
PS	1230	0.0117	0.0093	0.0076	0.0038
PS/LAI	1230	.0220	.0094	.0047	.0032
PS	1245	.0115	.0091	.0075	.0037
PS/LAI	1245	.0216	.0092	.0046	.0032
PS	1300	.0111	.0089	.0072	.0036
PS/LAI	1300	.0210	.0089	.0045	.0031
PS	1315	.0110	.0088	.0072	.0036
PS/LAI	1315	.0208	.0088	.0044	.0030
PS	1330	.0107	.0085	.0070	.0034
PS/LAI	1330	.0202	.0086	.0043	.0029
PS	1345	.0103	.0082	.0067	.0033
PS/LAI	1345	.0194	.0082	.0042	.0028
PS	1400	.0100	.0079	.0065	.0032
PS/LAI	1400	.0188	.0080	.0040	.0027
PS	1415	.0093	.0074	.0061	.0030
PS/LAI	1415	.0176	.0075	.0038	.0026
PS	1430	.0089	.0071	.0058	.0029
PS/LAI	1430	.0168	.0072	.0036	.0024
PS	1445	.0083	.0066	.0054	.0027
PS/LAI	1445	.0157	.0067	.0034	.0023
PS	1500	.0076	.0060	.0049	.0024
PS/LAI	1500	.0143	.0061	.0030	.0021
PS	1515	.0069	.0055	.0045	.0022
PS/LAI	1515	.0131	.0056	.0028	.0019
PS	1530	.0066	.0053	.0043	.0021
PS/LAI	1530	.0124	.0053	.0027	.0018
PS	1545	.0060	.0048	.0039	.0019
PS/LAI	1545	.0113	.0048	.0024	.0016
PS	1600	.0053	.0042	.0034	.0017
PS/LAI	1600	.0099	.0042	.0021	.0015

(cont.)

1/ Expressed as gm-cal/cm^2/min.

Table 5, cont.

	Time	Height intervals - cm. 265 - 225	225 - 175	175 - 100	100 - 20
PS	1615	0.0046	0.0037	0.0030	0.0015
PS/LAI	1615	.0087	.0037	.0019	.0013
PS	1630	.0039	.0031	.0025	.0013
PS/LAI	1630	.0074	.0031	.0016	.0011
PS	1645	.0030	.0024	.0020	.0010
PS/LAI	1645	.0057	.0024	.0012	.0008
PS	1700	.0024	.0019	.0016	.0008
PS/LAI	1700	.0046	.0019	.0010	.0007

A summary of photosynthesis by layers for the whole day was obtained next. The top curve, R_{io}, in figure 2, was expressed as a function of time by a quadratic expression of the following form:

$$R_{io}(t) = at^2 + bt + c \qquad [12]$$

where t is the absolute magnitude of the time from noon (EST) in minutes. The constants were evaluated for the curve giving:

$$R_{io}(t) = -7.12 \times 10^{-6}\, t^2 - 8.67 \times 10^{-4} t + 1.13 \qquad [13]$$

Then, rewriting [11] for 7% reflection:

$$Vn(z,t) = \left[1.00 - 0.07\right] V_{io}(z,t)\; e^{-k(265-z)} \qquad [14]$$

$$Vn(z,t) = \frac{0.93}{2}\left[-7.12 \times 10^{-6}\, t^2 - 8.67 \times 10^{-4} t + 1.13\right] e^{-k(265-z)} \qquad [15]$$

The total visible radiation above the crop from 0700 hrs. to 1700 hrs. was obtained by integrating $Vn(z,t)$ with respect to t from t = 0 to t = 300, and multiplying by 2, to cover both halves of the day. This time interval covered the period during which net radiation was positive; _i.e._, downward, at the upper surface of the crop canopy. (By integrating to t = 342 min., the total Vn for the whole day was obtained, that value being ~~148~~ 224 gm-cal/cm^2/day.)

Photosynthesis by layers was obtained by evaluating $Vn(z,t)$ at the appropriate levels within the crop, subtracting the value obtained at the lower boundary of a layer from the upper boundary, and multiplying by the photosynthetic efficiency, 0.0684.

The calculations are summarized in table 6 along with the potential photosynthesis/leaf area index ratios, PS/LAI. The computations show photosynthesis decreasing from layer to layer as it should, from the assumptions in its calculation. The PS/LAI decreased even more drastically down through the crop.

Potential transpiration at each 15-minute interval was determined from values of net radiation in figure 2, assuming that there was no flux of sensible

Table 6. Daily totals of net visible radiation Vn(z), potential photosynthesis PS, and potential photosynthesis/ leaf area index PS/LAI in Ellis Hollow corn September 10, 1961.

Height cm.	Vn(z) 1/ (gm-cal/cm^2/day)	PS 2/ (gm-cal/cm^2/day)	PS/LAI 3/ (gm-cal/cm^2/day)
265	219		
265 - 225		4.95	9.34
225	147		
225 - 175		3.94	3.98
175	89		
175 - 100		3.23	2.00
100	42		
100 - 20		1.60	1.37
20	19		

1/ Total Vn(z) absorbed in crop = 200 gm-cal/cm^2.

2/ Total PS = 13.72 gm-cal/cm^2.

3/ Total PS/total LAI = 3.19 gm-cal/cm^2.

heat to or from the crop. Actually, there was probably a transfer of sensible heat from the crop, which means the potential transpiration values are probably high. The difference between the net radiation values at the two boundaries of a layer gives the potential transpiration from that layer. Potential transpiration/leaf area index (T/LAI) and potential transpiration/potential photosynthesis (T/PS) ratios were also calculated (table 7.)

Potential soil evaporation (E) was calculated from the differences in net radiation at 20 cm. and soil heat flux, subject to the following assumptions:

1. Net radiation at 20 cm. is approximately equal to net radiation at the soil surface. This seems like a good assumption since there is negligible leaf area below 20 cm.
2. Sensible heat loss from the soil surface to the air is neglible. This may be a poor assumption, particularly for a dry soil, or for high air velocities near the soil.
3. No energy flux as measured by the soil heat flux transducers buried at 2 cm. depth goes into evaporation. This assumption is good for soil with a moist surface, but is likely to be poor for a drier soil where evaporation takes place below the soil heat flux transducers.

The energy budget equation at the soil surface is:

$$Rn(z=0) = E + H + S \qquad [16]$$

where:

Rn = net radiation

E = evaporation

S = storage in soil

H = sensible heat flux to air

z = height in crop

The assumptions leave an expression:

$$E = Rn(z=20) - S \qquad [17]$$

Table 7. Potential transpiration (T), potential transpiration/leaf area index (T/LAI), and potential transpiration/potential photosynthesis (T/PS) within a corn crop canopy, Ellis Hollow, September 10, 1961[1]

	Height - cm.				
	265 - 225	225 - 175	175 - 100	100 - 20	20 - soil[2]
	1230 hrs. Rn(z max) = 0.78 E/ET = 0.15				
T	0.23	0.16	0.17	0.06	0.11
T/LAI	.43	.16	.11	.05	
T/PS	20	17	22	16	
	1245 hrs. Rn(z max) = 0.76 E/ET = 0.16				
T	0.23	0.15	0.16	0.06	0.11
T/LAI	.43	.15	.10	.05	
T/PS	20	16	21	16	
	1300 hrs. Rn(z max) = 0.73 E/ET = 0.15				
T	0.22	0.15	0.15	0.06	0.10
T/LAI	.42	.15	.09	.05	
T/PS	20	17	21	17	
	1315 hrs. Rn(z max) = 0.71 E/ET = 0.15				
T	0.22	0.14	0.15	0.05	0.10
T/LAI	.42	.14	.09	.04	
T/PS	20	16	21	14	
	1330 hrs. Rn(z max) = 0.68 E/ET = 0.16				
T	0.21	0.14	0.14	0.05	0.10
T/LAI	.40	.14	.09	.04	
T/PS	20	16	20	15	
	1345 hrs. Rn(z max) = 0.64 E/ET = 0.17				
T	0.20	0.13	0.13	0.04	0.10
T/LAI	.38	.13	.08	.03	
T/PS	19	16	19	15	

(cont.)

1/ T and T/LAI are expressed in gm-cal/cm^2/min.

2/ The 20-cm. - soil column contains potential evaporation.

Table 7, cont.

	Height - cm. 265 - 225	225 - 175	175 - 100	100 - 20	20 - soil[3/]
		1400 hrs. Rn(z max) = 0.61 E/ET = 0.14			
T[4/]	0.19	0.13	0.12	0.04	0.08
T/LAI	.36	.13	.07	.03	
T/PS	19	16	18	13	
		1415 hrs. Rn(z max) = 0.57 E/ET = 0.15			
T	0.18	0.11	0.12	0.04	0.08
T/LAI	.34	.11	.07	.03	
T/PS	19	15	20	13	
		1430 hrs. Rn(z max) = 0.53 E/ET = 0.14			
T	0.17	0.11	0.10	0.04	0.07
T/LAI	.32	.11	.06	.03	
T/PS	19	15	17	14	
		1445 hrs. Rn(z max) = 0.48 E/ET = 0.14			
T	0.15	0.09	0.10	0.04	0.06
T/LAI	.28	.09	.06	.03	
T/PS	18	14	19	15	
		1500 hrs. Rn(z max) = 0.44 E/ET = 0.15			
T	0.04	0.09	0.08	0.03	0.06
T/LAI	.26	.09	.05	.03	
T/PS	18	15	16	13	
		1515 hrs. Rn(z max) = 0.39 E/ET = 0.17			
T	0.13	0.07	0.07	0.03	0.06
T/LAI	.25	.07	.04	.03	
T/PS	19	13	16	14	
		1530 hrs. Rn(z max) = 0.34 E/ET = 0.16			
T	0.11	0.06	0.07	0.02	0.05
T/LAI	.21	.06	.04	.02	
T/PS	17	11	16	10	

3/ The 20 cm. - soil column contains potential evaporation

4/ T and T/LAI are expressed in gm-cal/cm^2/min.

Table 7, cont.

	Height - cm. 265 - 225	225 - 175	175 - 100	100 - 20	20 - soil[5/]
	1545 hrs. Rn(z max) = 0.29 E/ET = 0.19				
T[6/]	0.09	0.06	0.05	0.02	0.05
T/LAI	.17	.06	.03	.02	
T/PS	15	12	13	11	
	1600 hrs. Rn(z max) = 0.24 E/ET = 0.18				
T	0.08	0.04	0.05	0.01	0.04
T/LAI	.15	.04	.03	.01	
T/PS	15	10	15	6	
	1615 hrs. Rn(z max) = 0.19 E/ET = 0.18				
T	0.06	0.03	0.04	0.01	0.03
T/LAI	.11	.03	.02	.01	
T/PS	13	8	13	7	
	1630 hrs. Rn(z max) = 0.19 E/ET = 0.18				
T	0.06	0.03	0.04	0.01	0.03
T/LAI	.11	.03	.02	.01	
T/PS	15	8	16	8	
	1645 hrs. Rn(z max) = 0.13 E/ET = 0.18				
T	0.02	0.02	0.01	0.00	0.01
T/LAI	.04	.02	.01	.00	
T/PS	7	8	5	-	

5/ The 20 cm. - soil column contains potential evaporation

6/ T and T/LAI are expressed gm-cal/cm^2/min.

The first assumption seems valid at all times. The validity of the second and third assumptions rests to a large extent upon whether the soil is wet or dry. If the two second assumptions do not hold, at least they are partially compensated for in the equation above; *i.e.*, measured S will be too large, but H will not have been accounted for. Under most conditions, it appears likely that soil evaporation would be overestimated.

In addition to potential soil evaporation, the ratio of potential evaporation to potential evapotranspiration (E/ET) was calculated for each 15-minute interval from 1230 hrs. to 1700 hrs. (table 7.)

To compare water use per unit of photosynthesis, potential transpiration/potential photosynthesis ratios (T/PS) were calculated for each layer at 15-minute intervals. The daily potential transpiration and the soil evaporation were calculated from curves drawn in figure 2. A quadratic expression of the form $Rn = at^2 + bt + c$ was assumed for net radiation at each level within the crop. The constants, a, b, and c, were evaluated for each level (table 8.) The area under each curve was found by integrating the quadratic expression with respect to time (t). Then potential transpiration was found for each layer by subtracting the integral of the upper curve from the lower curve. These computations, plus T/LAI, T/PS, layer by layer, and E/ET and T/PS for the whole crop are included in table 9.

A plot of net radiation vs height (figure 8) showed net radiation to decrease exponentially within the crop except at the lower depths. Data for two times, 1200 hrs. and 1430 hrs., taken from the curves in figure 2, and the whole day's net radiation, showed this relationship. The three plots were quite similar, each showing a positive deviation of net radiation penetration down at 20 cm.

C. Discussion of Water Use

Potential transpiration/potential photosynthesis ratios were generally about equal through the crop. The differences that do occur are rather consistent, layer by layer, throughout the day, but these differences are likely to reflect errors in assumptions used in the calculations, or construction of the Rn curves in

Table 8. Evaluated constants used in the net radiation equation $Rn = at^2 + bt + c$, where t is the absolute magnitude of the time in minutes from 1200 hrs., EST, September 10, 1961.

Height (cm)	a	b	c
265	-4.89×10^{-6}	-11.0×10^{-4}	0.80
225	-2.67×10^{-6}	-10.0×10^{-4}	.57
175	-1.78×10^{-6}	-7.00×10^{-4}	.40
100	-0.889×10^{-6}	-4.00×10^{-4}	.23
20	-0.445×10^{-6}	-3.33×10^{-4}	.18
nil	-0.222×10^{-6}	-1.00×10^{-4}	.06

Table 9. Daily total potential transpiration (T), potential soil evaporation (E), potential transpiration/leaf area index (T/LAI), and potential transpiration/potential photosynthesis (T/PS) for corn canopy at Ellis Hollow, Ithaca, N.Y. September 10, 1961[1/]

	Height - cm.				
	265 - 225	225 - 175	175 - 100	100 - 20	20 - soil
T	89	59	59	16	47
T/LAI	168	60	37	14	
T/PS	18	15	18	10	

E/ET = 0.17   Average T/PS = 16

1/ All values with units are in gm-cal/cm^2/day.

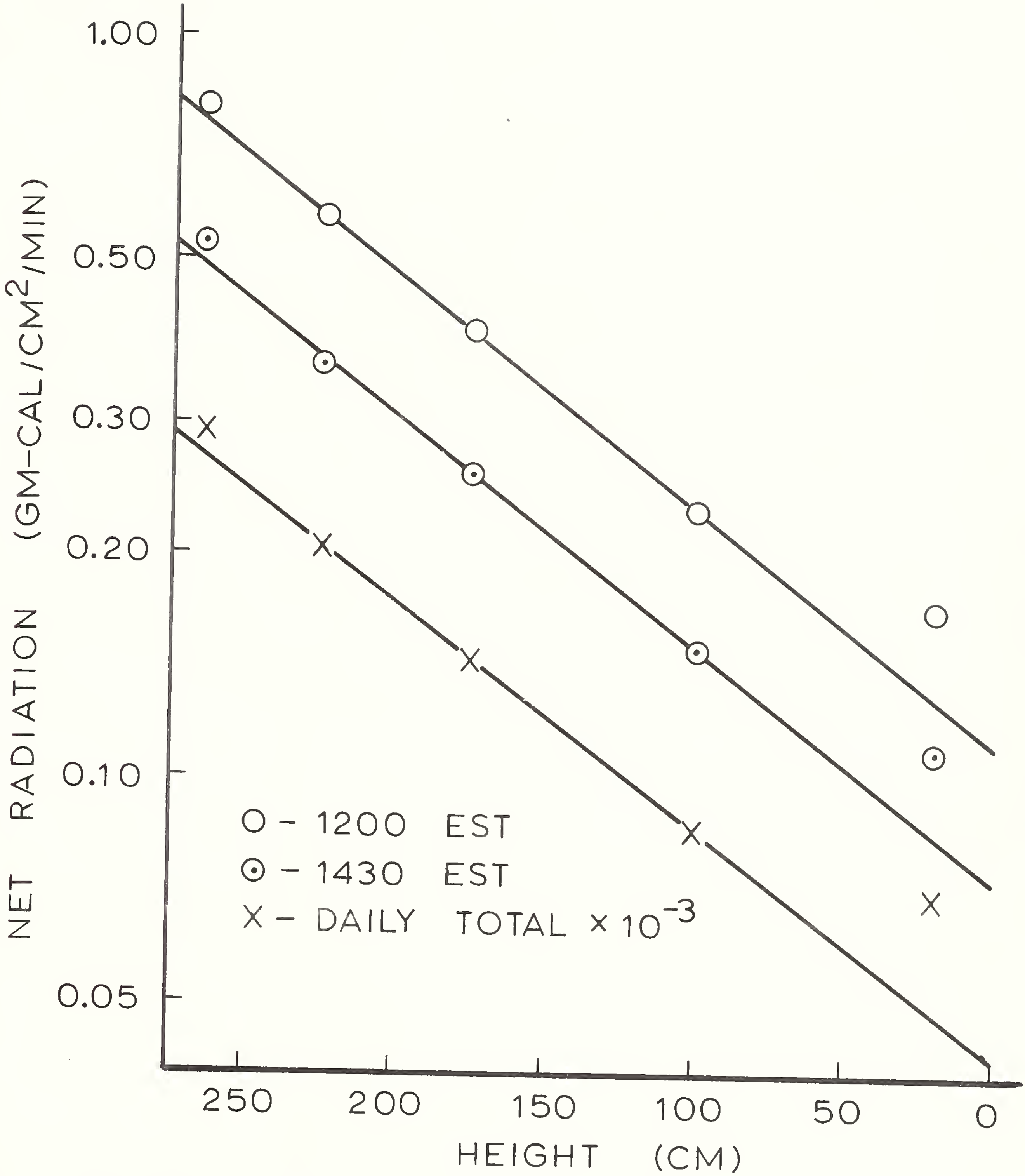

FIGURE 8-CALCULATED NET RADIATION VS HEIGHT IN MATURE ELLIS HOLLOW CORN, SEPT. 10, 1961

figure 2, rather than actual differences in these ratios. The lowest layer in crop canopy may be an exception. There, the potential transpiration-potential photosynthesis ratio may actually be lower than the ratios higher in the crop. However, since the calculations were based on figure 2, the low values of the ratio may be introduced from an error in constructing the curve for net radiation at 20 cm.

Potential transpiration/potential photosynthesis (T/PS) decreased as the time from solar noon increased. That this is true is easily seen from figure 2 where net radiation approaches zero at 1700 hrs., whereas incident short-wave length radiation is still up at 0.23 gm-cal/cm^2/min. In the 0700 to 1700 hr. period, potential transpiration/potential photosynthesis was 16. This value is probably slightly high, since sensible heat flux, evaporation of dew in the morning, and photosynthesis occurring at zero or negative values of net radiation were not taken into account.

The portion of potential evapotranspiration that is due to evaporation from the soil ranged from 14% to 19% on the 15-minute interval calculations. The complete day calculations showed E/ET = 17%. This low figure is assumed to be due to the dense shading afforded by the crop canopy. It actually could be lower or higher depending upon the validity of the assumptions used in calculating E and ET.

SUMMARY

Data were collected which gave sinks for shortwave radiation within a corn crop. Net radiation above a corn crop canopy, and at four levels within the crop, 225, 175, 100, and 20 cm.,, were collected for the afternoon of September 10, 1961. The data were extrapolated back through the morning hours.

Transmission measurements with a Miller field light transmission photometer showed that shortwave transmission can be expressed as an exponential function of height, as well as leaf area index. For this full-grown corn, a trigonometric expression was derived relating cumulative leaf area index to height.

From the net radiation data collected, net thermal radiation was calculated at the five levels at 15-minute intervals from 1230 to 1700 hrs. Net thermal radiation was an exponential function of height down through 100 cm. Anomalies appearing in the net thermal radiation profiles around noon-time were attributed to leaf and row orientation effects.

A photosynthetic efficiency of 6.84% was obtained from harvested plant dry matter accumulation data. Using Beer's law for light absorption, potential photosynthesis by layers was calculated for each 15-minute interval, and for the whole day. Likewise, using net radiation data, potential transpiration by layers was calculated. On a daily basis, the potential transpiration/potential photosynthesis ratio was 16 on an energy basis.

From soil heat flux data, soil evaporation was calculated, subject to the assumptions made. For the whole day it was estimated that 17% of the total evapotranspiration could be direct evaporation from the soil.

LITERATURE CITED

1. Billings, W.D. and Morris, Robert J. Reflection of visible and infrared radiation from leaves of different ecological groups. Amer. Jour. Bot. 38: 327-331. 1961.

2. Denmead, O.T., Fritschen, L.J., and Shaw, R.H. Spatial distribution of net radiation in a cornfield. (Accepted for Agron. Jour. 1962)

3. Fritschen, L.J. Construction and calibration details of the thermal-transducer type net radiometer. Bul. Amer. Meteor. Soc. 41: 180-183. 1960.

4. Gates, David M. and Tantraporn, Wirojana. The reflectivity of deciduous trees and herbaceous plants in the infrared to 25μ. Science 115: 613-616. 1952.

5. Gerber, J.F. and Decker, W.L. Evapotranspiration and heat budget of a cornfield. Agron. Jour. 53: 259-261. 1961.

6. Graham, W.G. and King, K.M. Fraction of net radiation utilized in evapotranspiration from a corn crop. Soil Sci. Soc. Amer. Proc. 25: 158-160. 1960.

7. Miller, Edward E. Averaged measurement of optical transmission. Rev. Sci. Instruments. 22: 56-57. 1961.

8. Monteith, J.L. The reflection of short-wave radiation by vegetation. Quar. Jour. Roy. Meteor. Soc. (London) 85: 386-392. 1959.

9. Rabideau, G.S., French, C.S. and Holt, A.S. The absorption and reflection spectra of leaves, chloroplast suspensions, and chloroplast fragments as measured in an Ulbricht sphere. Amer. Jour. Bot. 33: 769-777. 1946.

Literature Citations, cont.

10. Saito, T. On estimation of transpiration and of eddy-transfer coefficient within plant communities by energy balance method. Jour. Agr. Met.(Japan) 17: 101-105. 1962.

11. Shaw, R.H. Water use from plastic covered and uncovered corn plots. Agron. Jour. 51: 172-173. 1959.

12. Tanner, C.B. Energy balance approach to evapotranspiration from crops. Soil Sci. Soc. Amer. Proc. 24: 1-9. 1960.

13. Tanner, C.B., Peterson, A.E., and Love, J.R. Radiant energy exchange in a corn field. Agron. Jour. 52: 373-379. 1960.

14. Uchijima, Zenbei. On characterisitics of heat balance of water layer under paddy plant cover. Bul. Nat. Inst. Agri. Sci. (Japan). Series A No.8: 243-265. 1961.

15. Yocum, C.S., Allen, L.H., and Lemon, E.R. Photosynthesis under Field Conditions. VI. Solar radiation balance and photosynthetic efficiency. (For simultaneous publication in Agron. Jour.)

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PHOTOSYNTHESIS UNDER FIELD CONDITIONS: RADIANT ENERGY EXCHANGES WITHIN A CORN CROP CANOPY AND IMPLICATIONS IN WATER USE EFFICENCY
by L. H. Allen, C. S. Yocum, and E. R. Lemon
Interm Report 62-4, July 1962
23 pages
DA Task 3A99-27-005-08
Cross Service Order 2-62

Data are reported from net radiation measurements taken at five levels in a dense crop of corn. Net thermal radiation was calculated at the respective heights. Transmissiondata indicate that shortwave transmission can be expressed as an exponential function of height, as well as of cumulative leaf area index. Net thermal radiation has an exponential distribution except at low levels and at the top of the crop. Potential transpiration and potential photosynthesis were calculated.

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